TAILORING GROWTH MECHANISMS IN HETEROEPITAXY OF COMPLEX OXIDES

R. Bachelet [(1)], *F. Sanchez* [(1)], *J. Santiso* [(2)], *and J. Fontcuberta* [(1)]

[(1)] *Institut de Ciencia de Materials de Barcelona, ICMAB-CSIC, Campus UAB, 08193 Bellaterra, Spain*
[(2)] *Centro de Investigación en Nanociencia y Nanotecnología, CIN2, ICN-CSIC, Campus UAB, 08193 Bellaterra, Spain*
rbachelet@icmab.es

Complex oxides show an exciting variety of functional properties that make them extremely appealing for the development of new devices or improvement of current devices. The interest is even renewed after stimulating new results involving biferroic oxides and two-dimensional electron gases at oxide interfaces [1]. Properties of complex oxides usually depend greatly on small lattice distortions or chemical modifications. Whereas it can allow a fine control of the properties it also implies a very accurate control of the micro/nanostructure of the materials. Therefore, radical control of the oxides preparation is necessary. Particularly relevant is the precise control of the growth of epitaxial films. The understanding on oxide growth is still far from the understanding of epitaxy of semiconductors.

One of the most powerful tools to monitor in-real time the epitaxial growth is reflection high energy electron diffraction (RHEED). It can successfully used to control the epitaxy of complex oxides in spite of the high oxygen pressure usually required [2]. We have investigated heteroepitaxial growth (by means of pulsed laser deposition) of the ferromagnetic and conducting $SrRuO_3$ on $SrTiO_3$(001) substrates by means of RHEED and atomic force microscopy (AFM) with the objective of controlling the growth mechanisms. This is a key to fabricate heterostructures with atomically flat interfaces and with real-time control of the thickness at a submonolayer level. We will show that the control is achieved by i) control of diffusivity and density of the growing species, and ii) control of the step morphology of substrate and growing film.

A typical AFM topographic image of a $SrTiO_3$(001) with a TiO_2-termination is in Figure 1a. Terraces around 280 nm wide are separated by steps of 1 u.c. in height. The substrate surface is later in-situ checked by means of RHEED (Figure 1b). The straight substrate steps favour $SrRuO_3$ nucleation on the terraces, this is verified in real time by the RHEED oscillations that signal layer-by-layer growth (see the zoom of the curve in Figure 2b). The growth mode is ex-situ confirmed by AFM (Figure 2e). The formation of twp-dimensional islands causes a progressive step meandering, which favours a transition to step-flow growth mechanism [3,4]. This is illustrated in the RHEED intensity recovery after each laser pulse (Figure 2c) and ex-situ confirmed by AFM (Figure 2f). From intensity recovery curves diffusivity coefficients can be determined. We will show also that growth interruption during a few minutes causes straightening of the steps, and as a result the terrace morphology is recovered (Figures 2d and 2g). This is relevant since it causes a re-entrant layer-by-layer mechanism. The growing layer morphology can then be tailored by the growth mechanisms, therefore allowing a selection of the film morphology before continuing growth of other top layers.

References:

[1] *Whiter Oxide Electronics?*, MRS Bulletin **33**, 11 (Special issue), November 2008
[2] G.J.H.M. Rijnders, G. Koster, D.H.A. Blank, H. Rogalla, Appl. Phys. Lett. **70**, 1888 (1997)
[3] G. Rijnders, D.H.A. Blank, J. Choi, C.-B. Eom, Appl. Phys. Lett. **84**, 505 (2004)
[4] R. Bachelet, F. Sánchez, J. Santiso, J. Fontcuberta, Appl. Phys. Lett. **93**, 151916 (2008)

Figures:

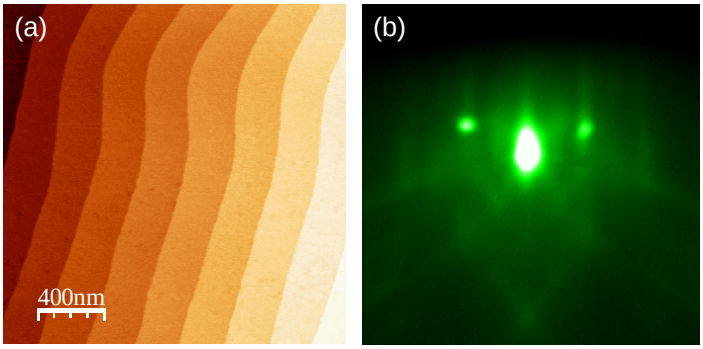

Figure 1: (a) Topographic AFM image of a $SrTiO_3$(001) substrate after chemical treatment to have unique TiO_2-termination. (b) RHEED pattern of a $SrTiO_3$(001) substrate.

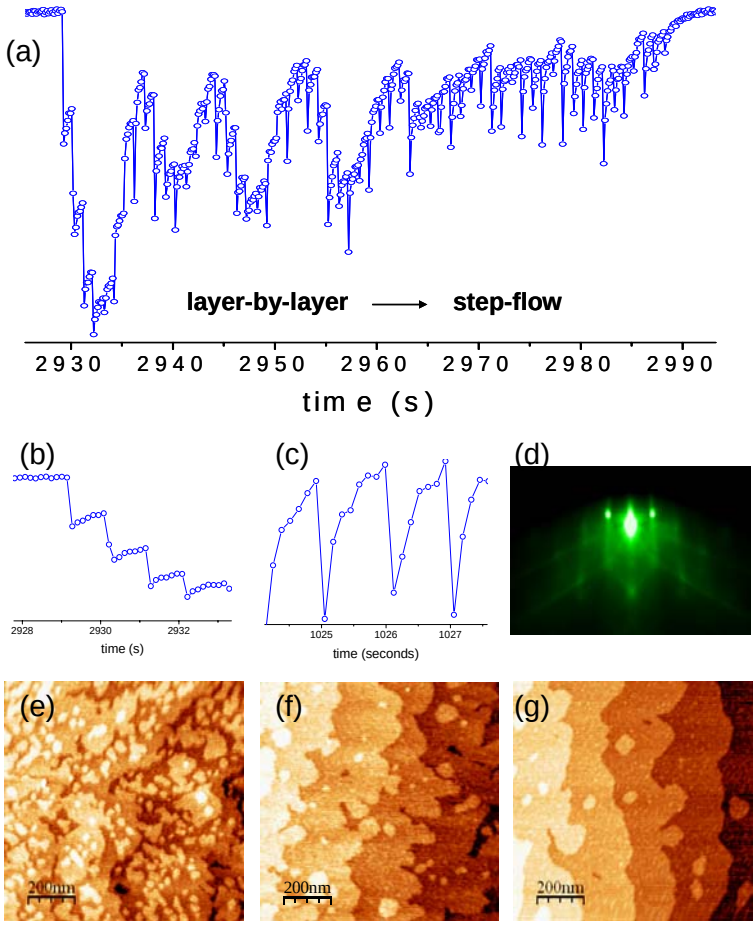

Figure 2: (a) Time-resolved RHEED intensity during $SrRuO_3$ growth: (b) in the layer-by-layer mode, (c) in the step-flow mode. (d) RHEED pattern of the growing $SrRuO_3$ layer. Corresponding topographic AFM images of the quenched film surface: (e) after a half monolayer deposition in the layer-by-layer mode, (f) in the step-flow mode and (g) after growth interruption of 15 minutes.